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Preliminary Systems Engineering Risk Assessment to Attain National Renewable Energy Generation Targets

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Abstract

Utilities have experienced an explosion in renewable energy generation (or, Variable Energy Resources (VER)). Governments have accelerated VER-derived power development with two key approaches: mandates with aggressive power generation targets; and, fiscal policies to offset high VER system costs. Much VER-related literature has examined those approaches, assumed their success, then predicted the expected benefits for social goals such as reducing green-house gases and air pollution. Relatively little work has considered how current VER technologies, integrated within power systems, could satisfy utility-scale generation targets. This study proposes a preliminary, independent view of the risk assumed by the United Kingdom in meeting its national VER-generation target based on historical performance and current operational data. The study considers changes in overall energy demand, VER capacity and VER generation to identify risks to meeting the specified targets. The study concludes by proposing further research areas, illustrating how Systems Engineering methods apply to nontraditional areas.

Keywords: Renewable power generation;Wind energy;Systems engineering;System modeling;Risk management

1. Introduction

Variable electrical resources (VER) technologies – the power-generating technologies of wind, solar, hydroelectric, tidal, ocean and more -- have exploded in installed capacity and actual generation. These developments reflect social motives such as reducing the green-house gas (GHG) emissions related to

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anthropogenic global warming (AGW) [1,2]; abating life-cycle pollution from conventional power generation [3]; and, developing national/regional energy sufficiency [4].

The bulk power delivery enterprise has significant challenges integrating VER technologies: environmental [5], integration [6,7], lifecycle cost [8-12], operational [13] and impacts to reliability [3, 6].Governments have offset these challenges with VER-tailored policies to improve integration [13]; VER-focused financial incentives [14]; mandates for utilities to buy VER-generated power [1, 2]; and, VER-favored indirect targets (e.g., GHG limits to reduce conventional power generation) [8-10].

Current research has addressed VER impacts on the energy enterprise in three ways: (a) component improvements [15]; (b) integration improvements: better operating procedures [16], enhanced transmission infrastructure, improved scheduling [13], topologies to improve VER support to overall demand [17]; and, (c) very high level concepts to rearchitect the energy enterprise with dominant, or even exclusive, VER-generated energy [3, 4, 18, 19].

This research often lacks the actual impacts of VER systems on today's power enterprise. Using actual VER system operational data over meaningful time periods could capture variability in demand, intermittency in generation and weather-related performance. Such data can prove elusive because of its confidential, or proprietary nature. Researchers have compensated by using summary statistics, simulations [16], or limited operational data. One study [5] used operational data over a lengthy period to characterize VER system performance. The systems engineering (SE) literature has rarely considered energy systems, with exceptions [20, 21]. SE methods could prove useful for an energy enterprise consisting, as it does, of interconnected systems with diverse components, complex interfaces, stringent reliability requirements and real-time operations.

This article proposes to apply SE risk management methods to the question: will the VER systems deployed in a given country meet target generation levels by the target date? This research proposes a preliminary review of the risk assumed by the United Kingdom (UK) to meet its national VER-generation target. The study uses historical performance and current operational data to consider overall energy demand, VER installations and VER generation to identify risks to meet the specified targets.

2. Source Data

Source data for the study came from the UK Balancing Mechanism Reporting Service under the responsibility of ELEXON, Inc., as the Balancing Mechanism and Settlement Code (BMSC) authority [22, 23]. The BMSC data reports on the entire UK national grid with five-minute instantaneous power values and half-hour delivered energy values (used in this study). Data began 01 November 2008. New data is posted quarterly. This study ended with data as of 31 June 2011.

BMSC data reflect generation metered on the national grid. If direct metering cannot occur (e.g., a small wind turbine behind a substation), that generation would either not appear in the data, or would be subsumed within another category. This process limits visibility to smaller generators.

BMSC distinguishes 12 different generation sources in its real-time data: four conventional generation types; nuclear; three two-way international connectors; (d) three VER technologies: hydroelectric (hydro), wind and pumped storage (PS, in which water is pumped up to a reservoir when power is less expensive, then released to produce hydroelectric power when electricity is more expensive); and, (e) "other," for which there was no data in the study period.

Official UK statistics provide historical insight to energy sources other than electrical for uses such as heating, transportation and smaller, off-grid energy generation.

3. National Renewable Energy Target

The European Union (EU)'s Directive 2009/28/EC of 23 April 2009 (EU 2009) mandated specific national targets for the EU to reach "a 20 % target for the overall share of energy from renewable sources and a 10 % target for energy from renewable sources in transport" by 2020 [1]. The Directive stipulated intermediate milestones, eligible generation methods (e.g., PS excluded) and reporting metrics. The EU also required each member nation to report by 2010 their national plan to reach their 2020 target: for the UK, eligible renewables need to provide 15% of total energy used. Figure 1 summarizes the EU-mandated 15% target for the UK, planned progress milestones and actual progress against their plan.

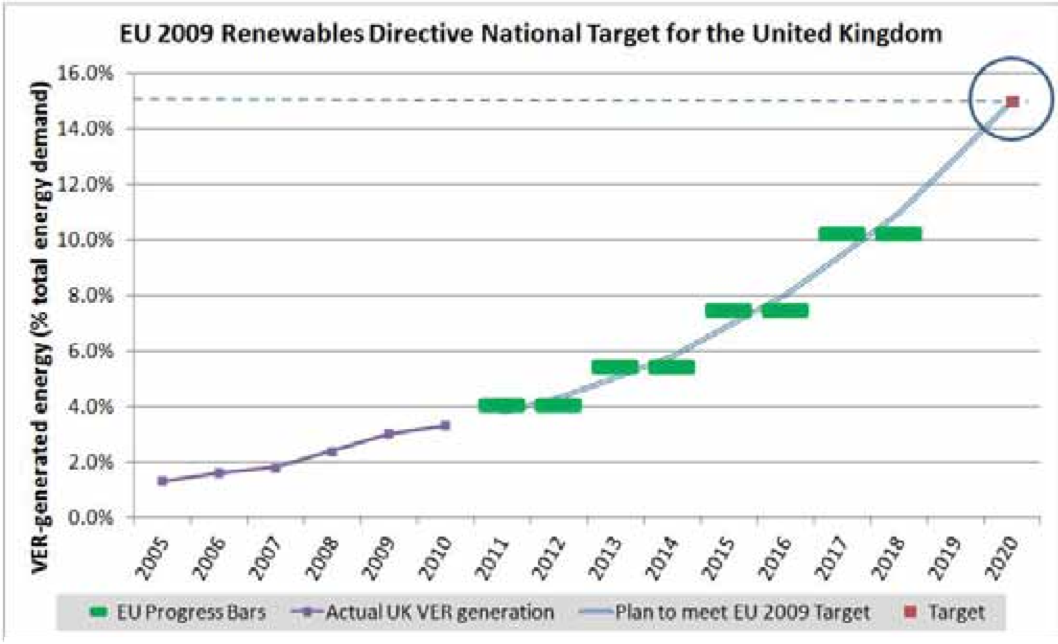

Figure 1: Plan vs. Actual Progress for UK's EU 2009 Renewables Target

The UK officially assessed its EU target in their 2010 report [24] as cautiously achievable. Subsequent official Government plans reflect an integrated effort to meet the EU 2009 Directive [9, 10].

4. SE Risk Assessments

The study considered potential risks to the system – the UK energy enterprise – to attain its EU 2009 target by using historical and current operational data to meet required total energy demand and supply VER-generated energy. Resulting risks and opportunities appear in braces with an identifier (e.g., {H1} is the first high risk).

This study will not address SE risk analysis, management and mitigation methods separately. Excellent overviews are available [25]. This study follows work on applying risk assessment to operational scenarios [26] and "due diligence" required in energy system investment [21].

5. Electrical power demand

The UK 2010 report [24] to attain the EU 2009 Directive assumed total demand decreased 0.4% annually. Historically, UK total energy demand trended up from 1980 to about 2005 at 0.5% annually, while total energy demand has fallen from 2005 to 2010 at 1.2% annually [27]. The margin between observed and planned reduction in total energy suggests opportunity to attain the EU 2009 target {O1}.

Electrical use increased 1.2% annually from 1970 to today [23, 27-31] with year-to-year variability as much as -5.9% to +6.7%. The UK report on long-term energy trends stated, "[O]verall demand for electricity may double by 2050 due to the electrification of the transport, heat and other carbon-intensive sectors" [8]. A uniform increase in electrical demand of 1.8% annually would double electrical demand. Thus, the electrical sector must increase at least 49% for 10 years, each year, compared to the long-term averages. This suggests high risk to the system {H1}.

The UK renewables roadmap states varying factors could impact UK total energy demand – "uncertainty around factors such as GDP growth, prices, consumer behaviour and the impact of energy efficiency policy" – indicate "a margin of uncertainty of at least +/- 8% from our 2020 central estimate" [10]. A review of historical data from 1948 onward [31] indicates the absolute bound on total energy demand would be +/- 12%. These two bounds suggest a medium risk to the system as shown in Table 1 with the two sets of outer bounds at +/- 8% and +/- 12% {M1}.

Table 1 Variability in UK Total Energy Demand and Its Impact on the EU 2009 Target

Total Energy Demand Case	% Total Demand Met by All VER System in 2020	Time Margin to EU 2009 Target (Years; Positive is before 2020, Negative is after 2020)	Supply Margin to EU 2009 Target (% Total Demand)
Base Case – 12%	17.0	+0.8	+2.0
Base Case – 8%	16.3	+0.6	+1.3
Central Estimate (Base Case)	**15.0**	----	----
Base Case + 8%	13.9	-0.5	-1.1
Base Case + 12%	13.4	-0.7	-1.6

Note Table 1 assumes (a) independence between energy demand and installation of VER power generation; and, (b) the UK meets its VER generation targets as stated in their 2010 assessment [24].

6. Renewable Energy Supply

The study next considered VER supply adequacy to meet the EU 2009 target. Figure 2 presents historical UK VER energy generation from all generating types (1990 to 2010) in Gigawatt-hours (GWh).

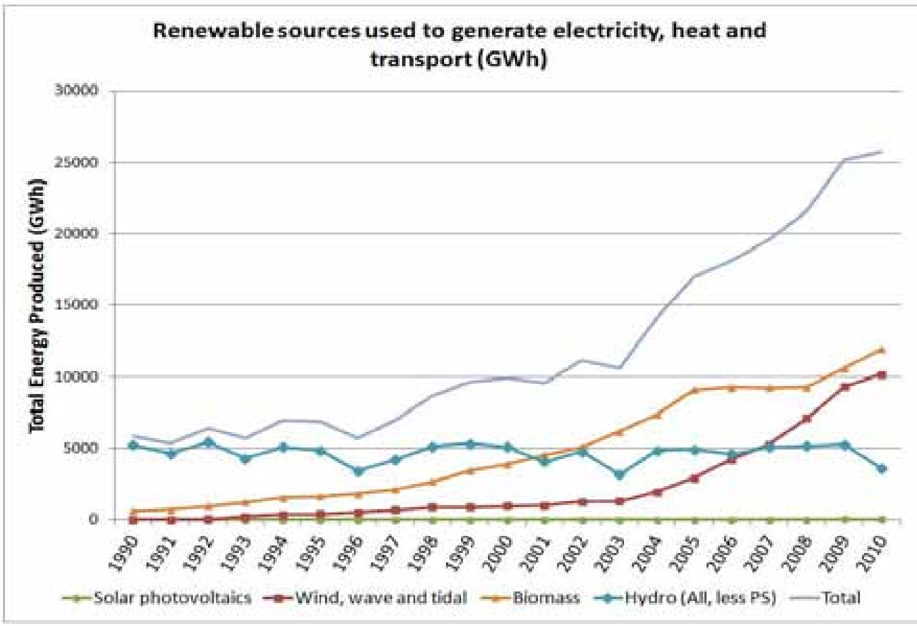

Figure 2: UK VER Energy Generation (GWh), 1990-2010, from [8]

The EU 2009 target and milestones require a 17.7% annual increase in total VER-generated energy, while the UK report to attain the EU 2009 target uses a 16.9% annual increase [1, 24], a difference of about 5%. This suggests a low risk to the system {L1}.

Figure 2 illustrates UK VER energy generation increasing annually 7.7% [8], substantially below the target attainment rate of 17.7% annually. This suggests a high risk to the system {H2}.

More VER generating capacity could increase total VER-generated energy [32] to meet overall energy demand. Figure 3 documents historical UK VER electrical generating capacity from 1950 onward.

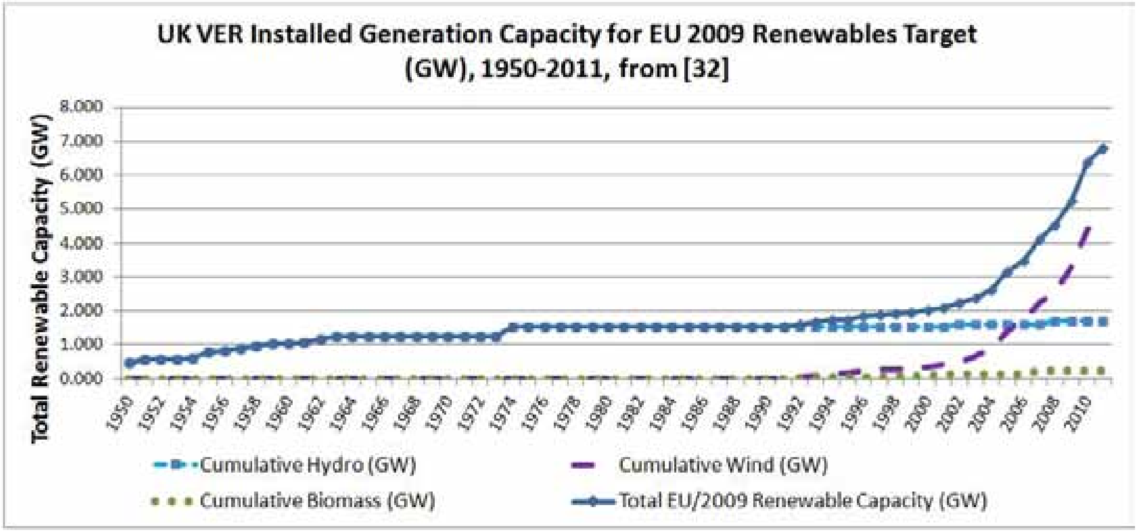

Figure 3: UK VER Electrical Capacity (GW), 1950-2011, from [32]

The long-term trend shows generating capacity grew 4.4% annually since 1950 and 7.3% annually since 1990, primarily due to wind generation. The disparity between the EU 2009 target generation rate of 17.7% annually and the rate to add electrical generation capacity suggests a high risk to the system {H3}.

A risk to the EU 2009 target arises by expecting increased VER generation to generate energy at the same rate as with earlier installations. Historical experience suggests: decreasing returns as favorable sites go (or, have gone); more co-located generators stressing transmission capabilities to limits; and, more local back-lash from aesthetic and local impacts [5, 33]. This suggests a medium risk to the system {M2}.

Another approach to increase VER generation comes from increasing technological capability to obtain more energy generation from the same number of generation units, or within the same foot-print [34]. A simple measure to assess technological maturity is capacity factor, defined as, "Energy produced by a generator as a percentage of that which would be achieved if the generator were to operate at maximum output 100% of the time" [35]. Expert opinions [11, 12, 15, 32, 35-38] suggest a range for capacity factors for UK VER systems as

- wind energy systems: 30% today, 35% by 2015 and 40% by 2020
- biomass systems: 54%
- hydroelectric systems: 41%
- other VER systems: negligible for this study

Since wind systems have had the greatest increase in installed capacity of any UK-based VER technology, the study will focus on wind systems and assume constant values for other VER technologies.

The BMSC data supports estimating the observed overall wind capacity factor ($\bar{X}$= 25.7%, $\hat{S}$ = 8.1%). Of the 32 months in the study data, 21 months are within one standard deviation, six months are more than one standard deviation below average, five months more than one standard deviation above average, and no months more than two standard deviations from the average. This data suggests the expert opinions are too generous, requiring a lower value for wind capacity factor closer to 26%. Table 2 catalogs the impact of improving capacity factor for wind from its observed value of 26% to the expert-based values.

Table 2 Impact of Improving Overall Installed Wind Capacity Factor on Attaining the UK's EU 2009 Target

Wind Capacity Case (All VER sources, Wind Capacity Factor Varied from Base Case)	% Total Demand in 2020	Time Margin to EU 2009 Target (Years; Positive is before 2020, Negative is after 2020)	Supply Margin to EU 2009 Target (% Total Demand)
Base Case (25%)	**15.0**	----	----
30% Capacity Factor	16.2	+0.5	+1.2
35% Capacity Factor	17.4	+1.0	+2.4
40% Capacity Factor	18.6	+1.4	+3.6
45% Capacity Factor	19.7	+1.7	+4.7

Note Table 2 assumes the 2010 total energy demand (central case) as forecast in [24]. Table 2 shows improving UK VER system technology supports reaching the EU 2009 target earlier, with more margin, compared to the baseline case. If the UK plan to meet the EU 2009 target assumed a wind capacity factor much more than 26%, this suggests a high risk to the system {H4}.

7. Preliminary risk assessment to meet the UK renewable target under EU 2009

This preliminary risk assessment indicates the UK could be at risk of failing to meet the EU 2009 target due to seven risks; and could have reduced risk to meet the target with one opportunity. The high-level risks follow from planning (1) to attain the EU 2009 target based on a 1.8% annual increase in electrical generation for 10 years, 49% above the long-term trend of 1.2% {H1}; (2) an annual rate of increase in VER generation of 17.7%, compared to the long-term historical increase in VER generation of 7.7% {H2}; (3) an annual rate of increase in VER production of 17.7%, compared to the long-term historical increase in VER generation capacity of 4.4% since 1950 and of 7.3% since 1990 {H3}; and (4) with wind system capacity factors of 30-35% from expert opinion, compared to operational data suggesting a wind capacity value of not more than 26% {H4}. The medium-level risks follow from planning (1) "a margin of uncertainty of at least +/- 8% from our 2020 central estimate" {M1}; and, (2) to have adequate resources for increased power generation, compared to expecting decreasing returns from lesser quality sites, added stress to existing transmission capabilities and local back-lash {M2}. The low risk follows from planning to use a 1 6.9% annual increase in total VER-generated energy, when the EU 2009 target requires achieving 17.7% annual increases {L1}. The opportunity to meet the EU 2009 t arget follows from planning for a decreasing demand of total energy demand at 0.4% annually compared to the trend of the last five years for total energy demand to fall at 1.2% annually {O1}.

8. Areas for further research

The study suggests five areas for further research: (1) develop risk analyses and mitigation plans for the seven risks and one opportunity identified in this study as in [21, 26] with Bayesian statistics to meld expert opinion with the observed probability distributions; (2) develop metrics for system reliability and energy extraction efficiency to compare competing, novel and refined VER technologies; (3) combine this preliminary assessment and (1) and (2) to create a model to assess practical and theoretical upper bounds for VER-generation in any geographical area; (4) use this operational data to build practical insight on the impacts of high levels of VER generation on reliability; and, (5) construct a life-cycle cost model to assess end-to-end costs for VER-generating systems, including the impacts of rare mineral constituents.

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